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POWER DIVISION

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BOYSEN DAM DIVERSION AND OUTLET WORKS

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Boysen Dam, a feature of the Missouri River Basin Project, is located on the Big Horn River in central Wyoming about 15 miles south of Thermopolis. The reservoir has a storage capacity of 1,493,000 acre-feet for irrigation, power production, silt control and flood control. A two-unit power plant of 15,000 kilowatt capacity will provide reasonably-priced power essential to the development of the area. Construction was started on a contract for the dam, power plant and relocation of the C.B.&Q. Railroad in the Fall of 1947, and was completed in February 1952.

The dam is an earth and rock-fill structure 218 feet in height above foundation. The spillway, outlet works, and power plant are all located on the right abutment where the foundation rock is of better quality than on the left abutment. The concrete-lined spillway, controlled by two 30-foot by 25-foot radial gates, will limit discharges to 20,000 cfs for downstream flood control. A novel feature of the 28-foot diameter diversion tunnel is its location underneath the spillway crest and chute so the spillway stilling basin could be used for diversion flows during construction. The outlet works are unusual in that a portion of an old railroad tunnel was salvaged and used to convey water under the dam by two pipes encased in concrete throughout the tunnel. A third feature that differs from the ordinary occurs at the power plant where the stilling basin for two 48-inch outlet valves is entirely within the powerhouse structure.

Diversion Works

The general layout of the diversion works is shown in Figure 1. The tunnel location under the left side of the spillway allowed flows through the diversion tunnel to discharge directly into the spillway stilling basin. The 28-foot diameter was adopted as this is the smallest size tunnel that would pass the largest flood of record without overtopping the cofferdam. The 55-foot-high cofferdam was made part of the main dam at the upstream toe.

Diversion flows are ordinarily passed through the outlet tunnel, but at Boysen Dam the old railroad tunnel that is used for the outlet works is too high above streambed for diversion. The cost of an alternate plan in which one tunnel provided for both outlets and diversion was found to be higher than the adopted plan with separate tunnels. A comparison was also made between the cost of the upstream channel open-cut excavation and the cost of tunnel excavation and lining. As the open cut was found to be more economical, the upstream channel was extended downstream as far as possible without endangering the spillway crest structure.

Excavation of the tunnel was performed without any unusual difficulties; however, 8-inch structural steel support beams were needed in the upstream section of tunnel between the portal and the upstream tunnel plug. The tunnel

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has a 15-inch minimum concrete lining that is reinforced only at the portals. Grouting was accomplished with rings of 20-foot grout holes between the upstream portal and the downstream end of the upstream tunnel plug. Longer holes were used where the tunnel intersected the main dam grouting curtain to help provide an adequate grout cut-off. Weep holes 10 feet deep were drilled through the concrete lining between the tunnel plugs to relieve any water pressure on the outside of the lining.

At the upstream tunnel plug shear keys were constructed to resist the full reservoir head. The 90-foot plug was placed in three 30-foot sections with provisions for grouting between the plug and tunnel lining after the concrete plug had cooled and contracted. The plug was artificially cooled by circulating river water through $\frac{3}{4}$ -inch pipe embedded in the concrete. Natural cooling would have required a year or more for a plug of this size. A cooling period of 45 days was originally specified for pipe at 5-foot spacing, but the actual cooling time was reduced to $14\frac{1}{2}$ days, by placing the pipe at 3-foot spacing. Cooling and grouting were not required at the downstream plug because it is not subjected to reservoir head and water tightness is not essential. The plug is needed to fill the diversion hole in the spillway floor and to support the foundation rock under the spillway side wall. A shaft and gallery permit access to the tunnel between the plugs. In addition, drain pipes were placed in the downstream plug and provisions were included for pumping water out of the tunnel if required for inspection or future grouting.

At the time the original plans were made for the diversion tunnel, it was assumed that all flow in the river could be stopped at the dam during the initial filling of the bottom 50 feet of reservoir between streambed and the invert of the upstream end of the penstock. Although the time required for this initial filling was shortened by releasing water from Bull Lake into Boysen Reservoir, communities downstream from the dam insisted that water be bypassed during the closure operations. Therefore, a 36-inch bypass pipe was embedded in concrete around the stop-log grooves at the upstream portal. A flap gate was installed at the upstream end of the pipe and provisions were made for closing the gate when the reservoir reached the elevation of the penstock. The stop logs were placed one at a time, causing only short stoppages of flow, until the water reached the 36-inch pipe. Flows through this pipe satisfied downstream requirements until sufficient water could be released through the penstock and outlet valves in the power plant. At that time the flap gate was closed and placing of concrete in the tunnel plugs was started. Leakage through the stop logs at the upstream portal was taken care of by a drain pipe in the first 30-foot section of the upstream plug. A valve at the upstream end of the drain pipe was closed just prior to the final concrete placement at the roof of the tunnel and the pipe was grouted.

Outlet Works

Before Boysen Dam was built the C.B.&Q. Railroad used a tunnel through the right abutment of the damsite. This tunnel was abandoned when the railroad was relocated around the reservoir and thus provided a ready-made tunnel for the 15-foot penstock and $5\frac{1}{2}$ -foot outlet pipe as shown in Figure 2. In addition to the tunnel, the outlet works include the intake structure with a bulkhead gate and access bridge, anchor blocks for the pipes downstream from the tunnel, and the power plant that houses the outlet valves and stilling basin as well as the turbines and generators. The 15-foot diameter was selected for the penstock because this was the largest pipe that could be installed

in the railroad tunnel without additional excavation. The smaller $5\frac{1}{2}$ -foot pipe is located directly above the penstock in the arched roof of the tunnel. The small pipe is required for reservoir releases at the time the penstock is bulkheaded for inspection or painting. Just upstream from the powerhouse the penstock branches three ways to two $10\frac{1}{2}$ -foot penstocks and one 4-foot 9-inch outlet pipe. This outlet pipe and the $5\frac{1}{2}$ -foot outlet pipe from the reservoir are controlled by 48-inch hollow-jet valves with 48-inch ring-follower emergency gates.

The intake structure for the outlet works is a conventional U-shaped tower with a 50-foot access bridge from the roadway at the spillway inlet wall. It supports the metal trashrack bars and is designed for an unbalanced hydrostatic head of 20 feet. A 15-foot by 19.64-foot bulkhead gate and its hoist at the intake can be used to close the entrance to either the 15-foot penstock or the $5\frac{1}{2}$ -foot outlet pipe. A room underneath the roof slab houses the compressor for the ice-prevention system. The system keeps ice from forming around the structure by releasing air below the surface of the reservoir. As the air bubbles up to the surface it brings the warmer reservoir water to the surface which melts the ice and effectively prevents the formation of new ice. A system of embedded pipes conveys air from the compressors to special air nozzles in the lower part of the intake structure.

Excavation for the intake structure exposed unstable shales in the upper part of the cut slopes with sound sandstone underneath. As the formations dip upstream toward the river, slides in this direction along the bedding planes could occur in the shales when they are saturated and lubricated by the reservoir water. To eliminate the possibility of slides at the intake, excavation in the shales below the maximum water surface was changed from $1\frac{1}{2}$:1 to 3:1 slopes, and riprap was placed on the slopes exposed to wave action in the vicinity of the intake. The structure was also moved 45 feet toward the spillway from its original location at the railroad tunnel to reduce excessive excavation on the flat 3:1 slopes. Although a short connecting tunnel was required between the intake and the railroad tunnel, the change allowed the inlet channel to connect with the upstream diversion channel, which resulted in an additional saving in excavation.

The original plan for the outlet tunnel had two $10\frac{1}{2}$ -foot penstocks in a $26\frac{1}{2}$ -foot wide by $20\frac{1}{2}$ -foot high modified horseshoe tunnel. This required considerable excavation at the sides of the existing railroad tunnel. As the tunnel was in badly jointed rock, excessive overbreak could be expected if the tunnel were widened. The adopted plan for the tunnel had a small $5\frac{1}{2}$ -foot outlet pipe above a 15-foot penstock. This plan did not require any excavation at the sides of the tunnel and eliminated this construction hazard. The old railroad tunnel was timbered throughout with solid lagging at the top. This timber was all removed before the pipes were installed and only a short section of tunnel caved in at the downstream portal. The caved portion was quickly repaired with structural steel supports. After the tunnel was filled with concrete around the pipes, the contact between the concrete and rock was grouted through a system of grout pipes and outlets. Upon completion of this grouting, rings of 20-foot deep grout holes, with one ring of 40-foot holes at the main grout curtain, were drilled and grouted in the part of the tunnel opposite the spillway crest.

The steel outlet and penstock pipes start 65 feet downstream from the intake structure and continue to the turbines and outlet valves. Although the penstock was designed for full hydrostatic head plus water-hammer, reinforcement was added to the concrete encasement because of the badly jointed rock.

At the outlet portal of the tunnel an anchor block was needed for the 22°43' vertical bend in the penstock. Access to the pipes was provided by a shaft from the top of this anchor block to manholes in the outlet pipe and penstock. The straight sections of pipe between the portal and power plant anchor blocks were encased in reinforced concrete and covered with backfill. At the power plant anchor block the penstock bifurcates into two 10½-foot penstocks, one for each turbine, with a ring seal emergency gate for each pipe just upstream from the turbines.

Provisions for a future surge tank were included in the anchor block at the power plant and consist of two inclined pipe connections from the two 10½-foot penstocks to the top of the block. These pipes will connect to a single steel surge tank that can be installed on top of the anchor if needed. It is not expected that a surge tank will be required; however, provisions for a future surge tank were added because they were relatively simple and inexpensive. If the regulating characteristics of the system prove to be unsatisfactory, a surge tank can be installed at that time.

The space available for the power plant was confined to the limited area on the right side of the spillway stilling basin and upstream from a faulted zone of foundation rock. The power plant is a standard indoor-type with two 10,500-hp turbines and two 7,500-kw generators. It has a rated head of 96 feet and an estimated annual output of 68,000,000 kwh. An unusual feature of the powerhouse is the provision for a stilling basin in the powerhouse below the main floors and adjacent to the turbines.

The stilling basin for the two 48-inch hollow-jet valves as shown in Figure 3 provide for the required discharge of 1,200 cfs at a head of 92 feet. At the maximum head of 134 feet the valves will discharge 1,460 cfs. Hydraulic model studies were used to determine the operating characteristics and adequacy of the stilling basin design. The first model that was tested was the standard hydraulic-jump type in which the floor just downstream from horizontal valves follows the trajectory of the jets until the depth required for a jump is reached. At this depth, the floor extends horizontally for a sufficient distance to obtain good stilling action. A satisfactory basin of this type needed a long basin that would extend beyond the powerhouse. As this would require a costly structure on a faulted rock foundation, it was desirable to develop a short basin that could be confined within the powerhouse.

Experiments with the model were continued in an attempt to find an adequate shorter basin. Turning the jets downward helped considerably, but surface velocities at the end of the powerhouse were found to be several times as high as those just below the surface and resulted in undesirable currents and surges in the tailrace. Attempts to smooth out the flow met with little success until a pair of converging walls, wedge-shaped in plan, were placed parallel to and downstream from the valves. In operation, the walls compressed the hollow jet from the sides as it passed between them and greatly improved the performance of the basin. Surface velocities at the end of the basin were much lower because of better vertical distribution, while waves and currents in the tailrace were negligible.

The effect of the converging walls in obtaining more efficient energy dissipation is not fully understood. It was apparent that the jet was protected by the side wedges and was able to penetrate into the basin for a greater depth and length which allowed turbulence and eddies in the lower part of the basin to help dissipate the energy. Combined with this effect, the compressing effect of the wedges reduced the amount of air in the core of the hollow jet. Thus, with less air being carried into the basin by the jet, there was less

tendency for the main flow to be carried to the surface by the entrained air. This reduced the surface velocities and disturbances as pointed out previously. Operation of the prototype has been very satisfactory since completion of the dam.

Engineering design and construction for the Bureau of Reclamation are under the direction of L. N. McClellan, M. ASCE, Assistant Commissioner and Chief Engineer. K. B. Keener, M. ASCE, is Chief Designing Engineer, and J. J. Hammond, M. ASCE, is Chief of the Dams Branch.

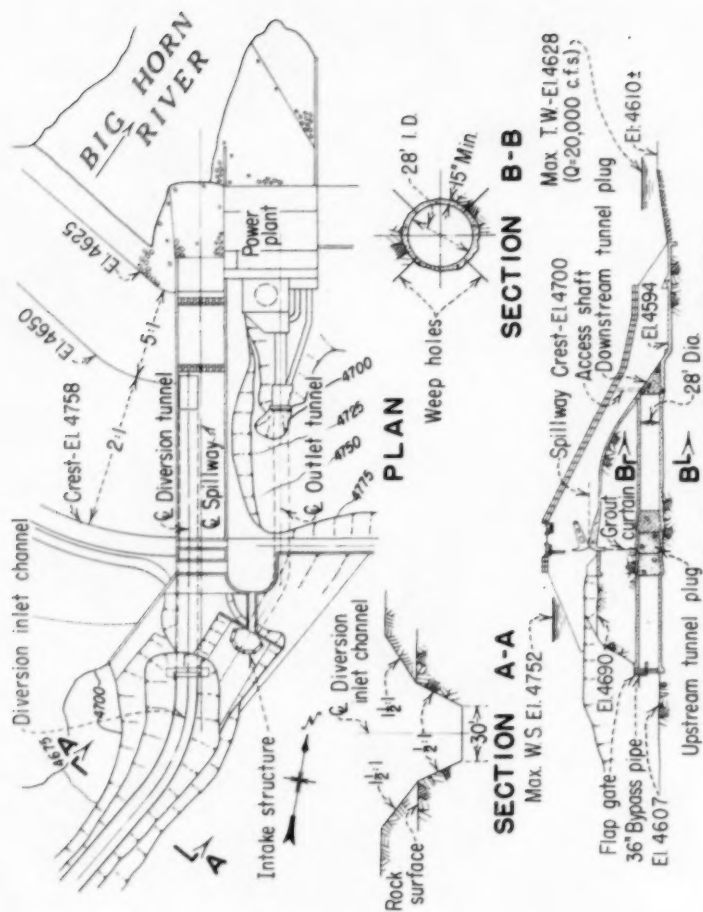
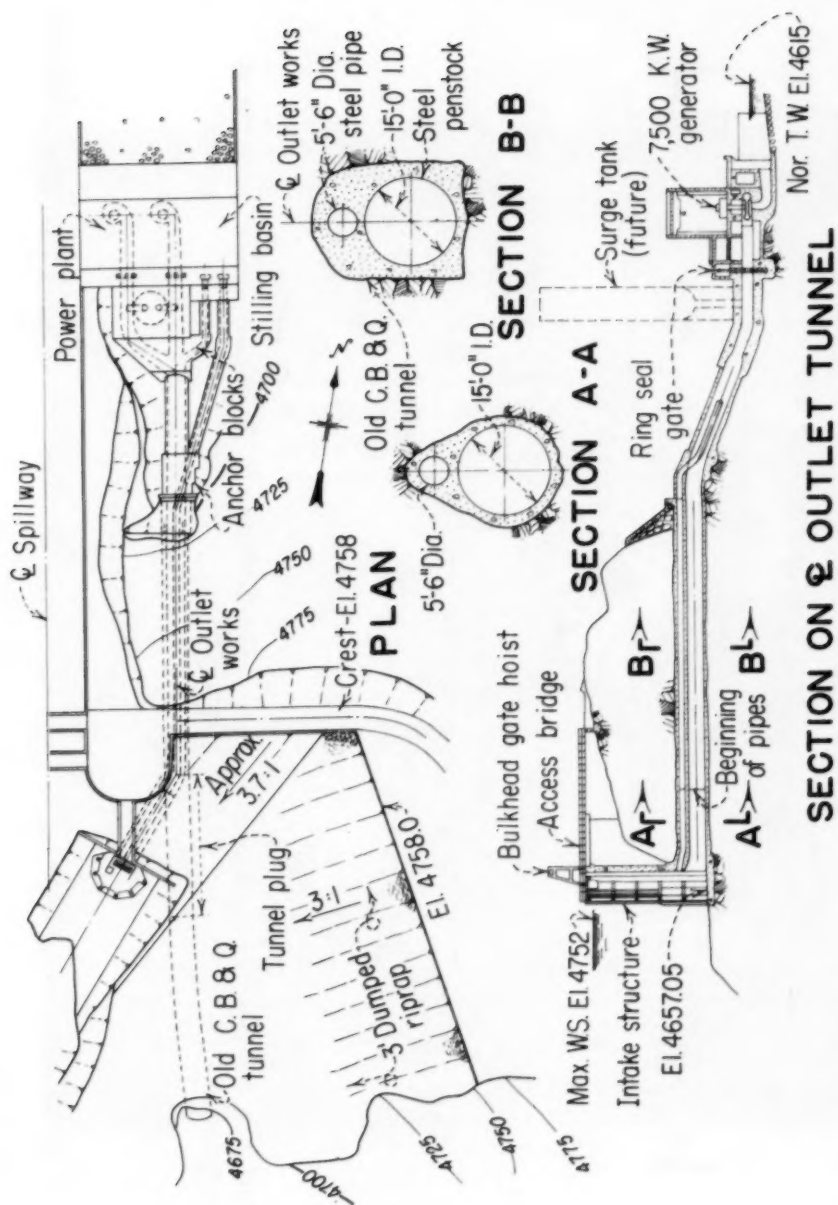


Fig. 1-Diversion tunnel located under spillway at Boysen Dam



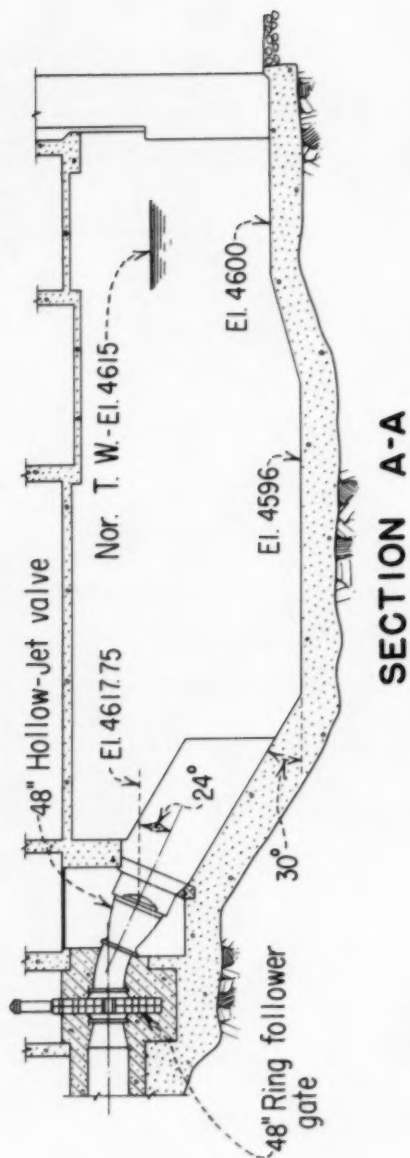
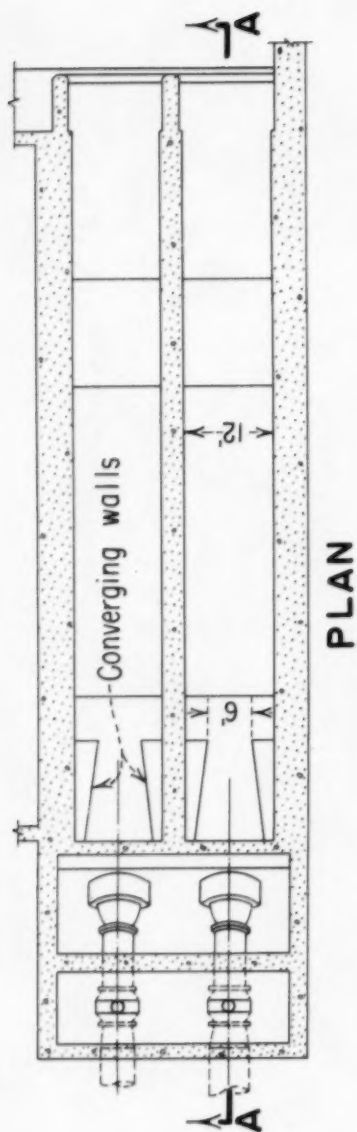


Fig. 3-Stilling basin for outlet works located in Boysen powerhouse

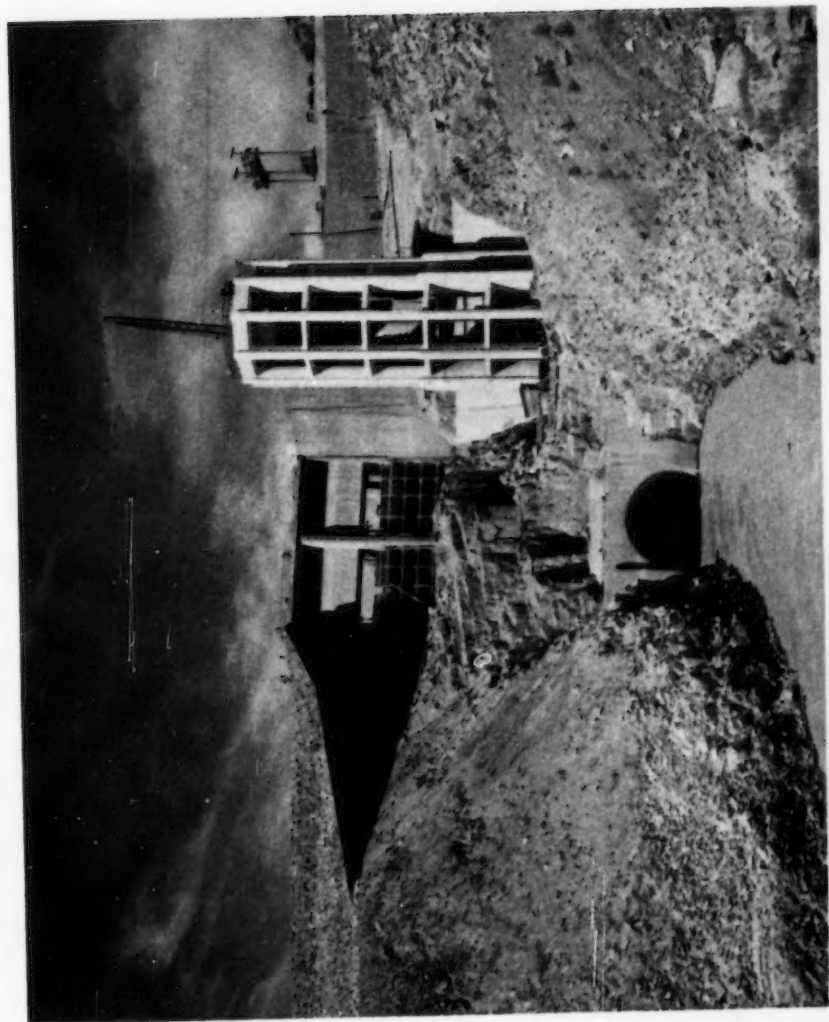


Fig. 4. Looking Downstream at the Spillway Inlet, Penstock Intake, and Diversion Tunnel at Boysen Dam.



Fig. 5. Boysen Dam and Power Plant Nearing Completion.